REPORT No. 138

THE DRAG OF C CLASS AIRSHIP HULL WITH VARYING LENGTH OF CYLINDRIC MIDSHIPS

By A. F. ZAHM, R. H. SMITH, and G. C. HILL
Bureau of Construction and Repair,
Navy Department

REPORT No. 138.

THE DRAG OF C CLASS AIRSHIP HULL WITH VARYING LENGTH OF CYLINDRIC MIDSHIPS.

By A. F. Zahm, R. H. Smith, and G. C. Hill.

SUMMARY.

A model of the C class airship hull, when severed at its major section and provided with a cylindric mid-body of variable length, had its air resistance increased about in proportion to the length of the mid-body up to 3 diameters, and in about the manner to be expected from the increase of skin friction on this variable length. For greater length the drag increased less and less rapidly.

As usual for such models, the drag for any fixed length, at 20 to 60 miles an hour, is accurately of the parabolic form $R \alpha V^n$, and hence the drag coefficient is of the hyperbolic form $C \alpha V^{n-2}$, where n is slightly less than 2.

The variation of C with length is stated in the conclusion.

INTRODUCTION.

This report[1] was submitted to the National Advisory Committee for Aeronautics for publication by permission of the Bureau of Construction and Repair, Navy Department. From previous tests, described in the bureau's Report No. 128, it was known that the C class airship hull, curving continuously from stern to stern, has an excellent shape coefficient. To ascertain whether this could be bettered by introducing a cylindric portion amidships, a new model was made and tested in the 8 by 8 foot tunnel for head-on resistance at 20, 30, 40, 50, and 60 miles an hour.

DESCRIPTION OF MODEL.

Figures 1 and 2 give the external appearance and over-all dimensions of this model; also the specified and measured offsets. The new hull, first made like the original, was severed at its major section, and elongated by inserting cylindric segments of various length and of the common diameter 7.7 inches. The segments, which were of dry pine, were provided with brass face plates inset into their ends in such way that the successive blocks could be screwed together so as to present a uniform and continuous outer surface. The exterior was smoothly sandpapered and varnished. The middle portions conformed accurately to specifications; but the bow and stern departed somewhat from the specified offsets, as may be seen in figure 2.

METHOD OF MEASUREMENT.

During the test the model was suspended by two fine short wires from a horizontal bar inside the wind shield shown in figure 1, the bar in turn being supported swing-like by two wires attached to the ceiling of a high room above the tunnel. Oscillations in yaw were prevented by a slender stern pin running through an eyelet in a taut horizontal wire. No drag corrections had to be made for this guide pin, as was proved by careful measurements. The drag correction for the static pressure drop along the axis of the tunnel was made as usual by multiplying the

[1] The present report is a slightly altered form of C. & R. confidential Report No. 176, revised for publication by the National Advisory Committee for Aeronautics.

volume of the model by the uniform pressure gradient. The drag was measured with the model supported first by two wires, then with two additional wires 10 diameters to one side of the others. The increment of resistance so found was subtracted from the original to determine the drag of the hull alone plus that of the horizontal bar to which the suspension wires were attached inside the wind shield. The slight resistance of this horizontal bar within the shield, and the pressure drop just mentioned, were then deducted to find the true drag on the hull alone. The wind speed could be held fixed and, after preliminary study, could be determined truly to one-half of 1 per cent in the region to be occupied by the model. The displacement of the model along stream could be measured with this precision at all the speeds employed above 30 miles an hour.

RESULTS OF THE TEST.

Figure 3 gives the net drag on the airship hull at all speeds from 20 to 60 miles an hour, with all lengths of cylindrical middle body from zero to 5 diameters. The straight lines in the lower part of the cut give the shape coefficient, plotted against VL as usual, for the model with the longest middle segment and with no middle segment. These two graphs do not blend because the hull shapes differ.

As usual in such experiments, the drag, for the range of speeds used, is accurately of the parabolic form $R=KV^n$, and hence the drag coefficient is of the hyperbolic form $C\alpha V^{n-2}$, where n is slightly less than 2. This method of plotting the air resistance and shape coefficient has been used for nearly two decades, and is known to give, for a certain speed range, straight line graphs for many other shapes besides surfaces of revolution.

The dots on the graphs in figure 3 represent corrected resistances. Each graph is derived from a separate sheet setting forth in detail the observations, as in figure 6. This and the seven other preliminary data plates, which latter are omitted for brevity, justify the placing of the dots in figure 3 all directly upon the straight line graphs. It is not, however, assumed that the straight line plot is applicable to indefinitely higher and lower speeds.

Figure 4 gives the total resistance of the model plotted against the length of the cylindrical middle. As the length of the cylindrical segment increases from 1 to 3 diameters, the increase of resistance is nearly uniform, and is approximately what should be expected from the increase of skin friction on this length. Beyond 3 diameters of length the rate of increase of total drag falls off more and more rapidly, due partly to the lessening of skin friction with length of surface and partly perhaps to the change of pressure distribution over the bow and stern. This fluctuation of pressure may in part cause the variations of n observable in figure 3.

As may be inferred from the nearly horizontal portion of this graph at the origin, a very short cylindrical segment will benefit the model more by increasing its volume than it will injure it by increasing its resistance. This inference is corroborated by the diagram in figure 5 giving the shape coefficient versus length of cylindrical middle portion. This diagram shows that the shape coefficient is improved with increase of straight middle body up to rather more than half a diameter, after which it slowly increases up to about 4 diameters, then declines with further increase of length as far as tested. The extreme length of the cylindrical portion was 5 diameters and the over-all length of the model was then 9.5 diameters. The indications are that the shape coefficient would continue to diminish with increasing length of middle body up to a fineness ratio too great for practical use.

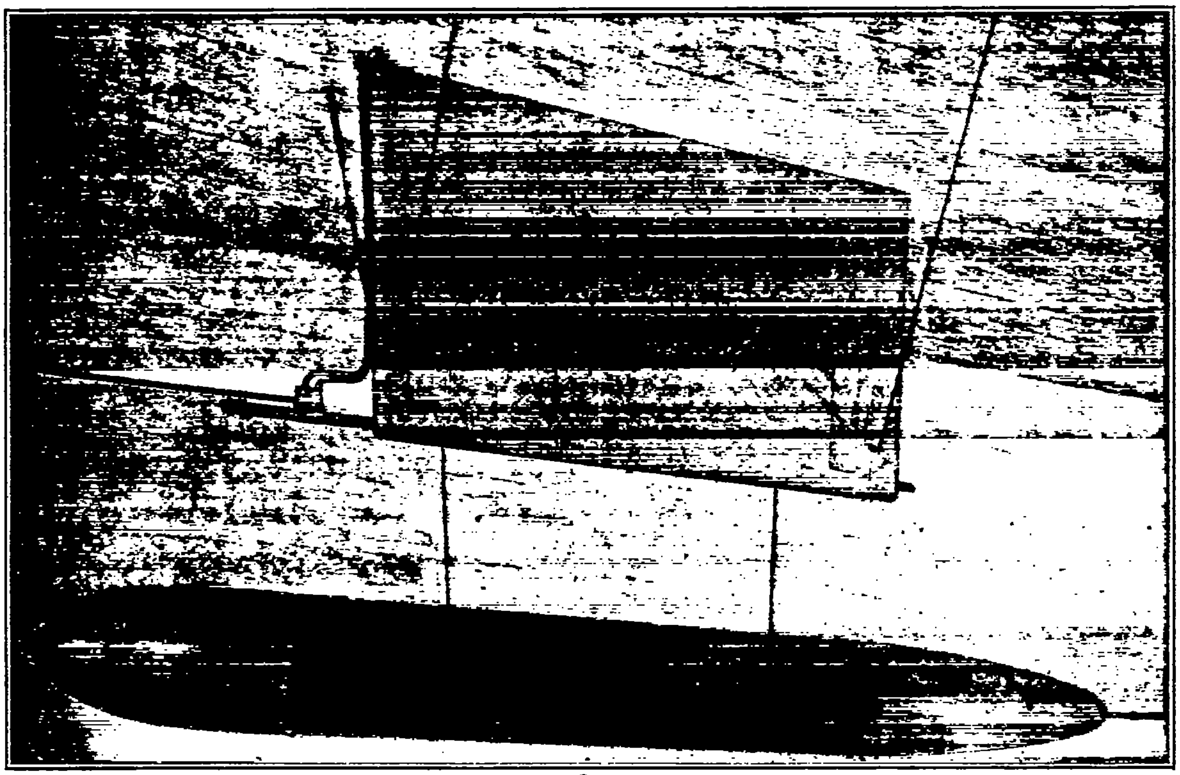

FIG. 1.—"C Class" airship hull with cylindric midship, suspended for drag measurements in wind tunnel.

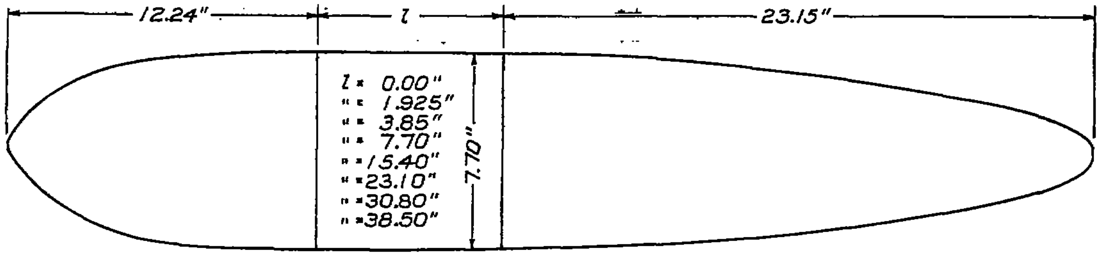

FIG. 2.—"C Class airship hull with cylindric midships. Chief dimensions.

[Maximum diameter, 7.7 inches.]

Diameter at station.	0	1	2	3	4	5	6	7	8	10	12	14	16	16.6	18	20	22
Specified	0	2.002	3.494	4.572	5.376	5.964	6.408	6.758	7.022	7.356	7.558	7.660	7.698	7.700	7.690	7.594	7.476
Actual	0	2.05	3.54	4.63	5.45	6.01	6.46	6.82	7.09	7.41	7.59	7.68	7.71	7.70	7.69	7.61	7.49
Diameter at station.	24	26	28	30	32	34	36	38	40	41	42	43	44	45	46	47	48
Specified	7.318	7.116	6.886	6.636	6.340	6.010	5.634	5.216	4.738	4.472	4.196	3.890	3.532	3.118	2.562	1.824	0
Actual	7.34	7.14	6.92	6.67	6.41	6.08	5.70	5.27	4.75	4.48	4.20	3.90	3.54	3.12	2.59	1.83	0

All dimensions in inches. Distance between stations=0.78782 inch.

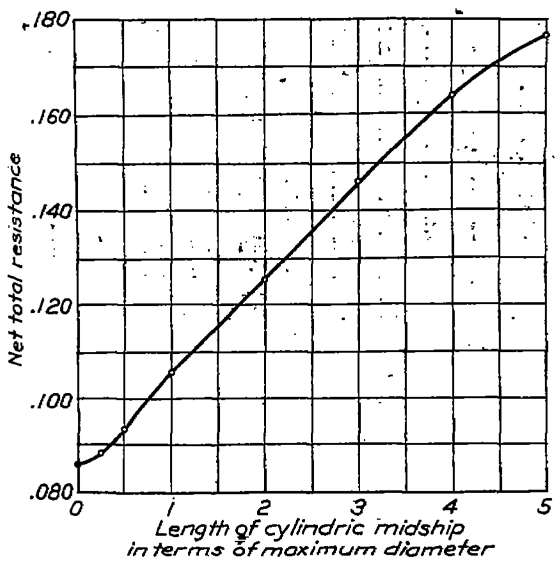

FIG. 4.—"C Class" airship hull with cylindric midships. Resistance versus midship length at 40 m. p. h.

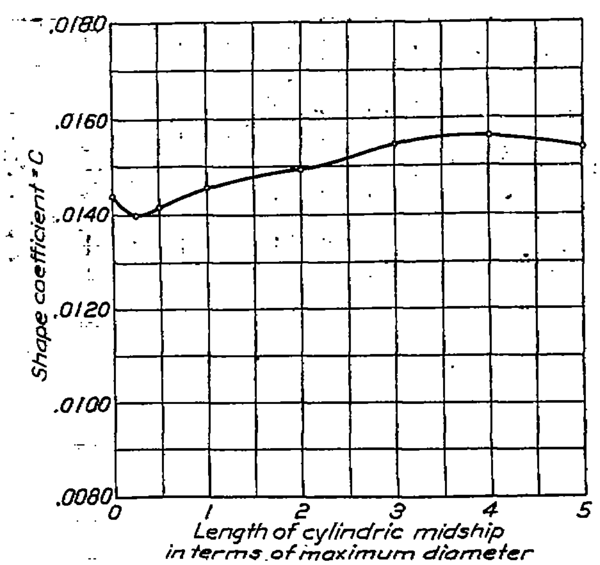

FIG. 5.—"C Class" airship hull with cylindric midships. Air speed 40 m. p. h.

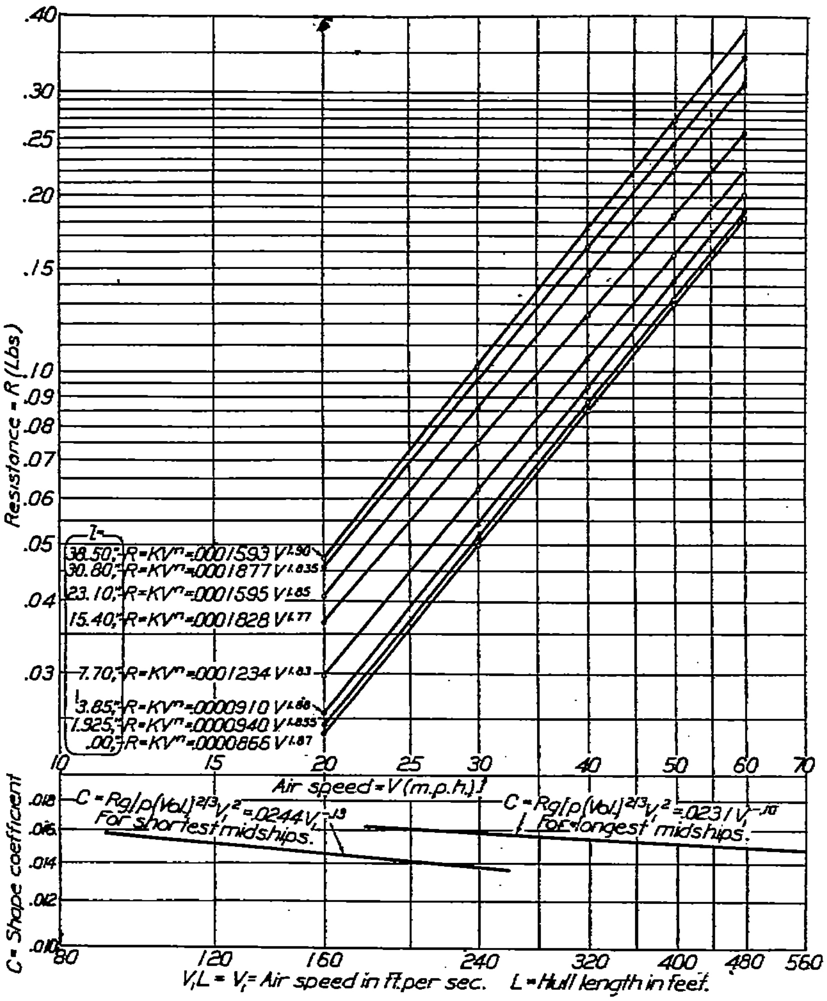

FIG. 3.—"'C Class" airship hull with cylindric midships. Resistance and shape coefficients for various midship lengths.

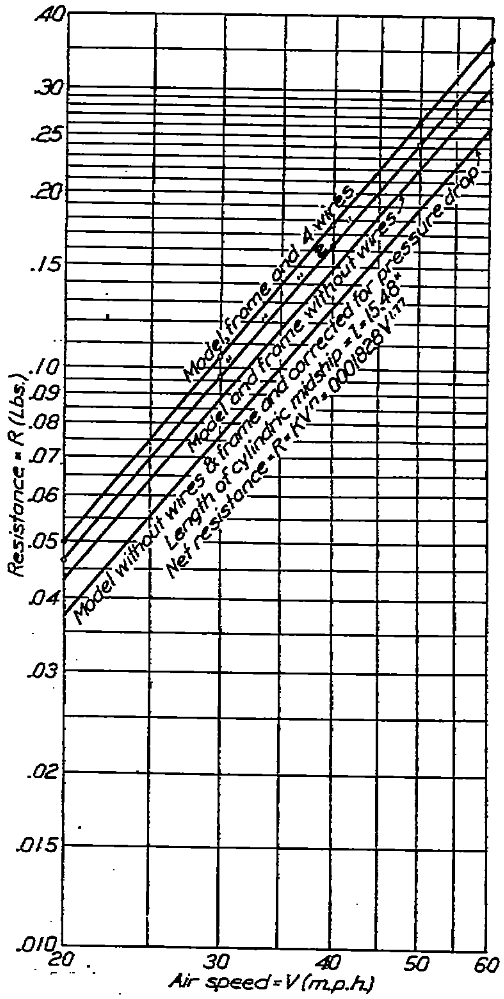

FIG. 6.—"C Class" airship hull with cylindric midships. Resistance at various wind speeds.

TABLE I.—*Resistance of C class airship hull.*

[Maximum diameter, 7.7 inches.]

Air speed (m. p. h.).	Displacement due to model and 4 wires (inches).	Corresponding resistance (pounds).	Displacement due to model and 2 wires (inches).	Corresponding resistance (pounds).	Resistance of model without wires (pounds).	Resistance due to frame (pounds).	Resistance due to pressure-drop (pounds).	Net total resistance (pounds).
Length of parallel middle body zero.								
20	0.313	0.0340	0.282	0.0307	0.0275	0.0008	0.0030	0.0237
30	.671	.0729	.601	.0653	.0581	.0019	.0063	.0499
40	1.151	.1251	1.039	.1129	.0998	.0036	.0103	.0859
50	1.759	.1912	1.572	.1709	.1515	.0059	.0153	.1303
60	2.462	.2676	2.203	.2395	.2130	.0089	.0210	.1831
Length of parallel middle body one-fourth maximum diameter of hull.								
20	0.305	0.0369	0.271	0.0328	0.0283	0.0008	0.0032	0.0243
30	.655	.0792	.577	.0698	.0602	.0019	.0068	.0515
40	1.123	.1358	.981	.1186	.1028	.0036	.0111	.0881
50	1.690	.2043	1.500	.1814	.1562	.0059	.0165	.1338
60	2.384	.2882	2.092	.2529	.2185	.0089	.0227	.1869
Length of parallel middle body one-half maximum diameter of hull.								
20	0.307	0.0391	0.269	0.0343	0.0295	0.0008	0.0034	0.0253
30	.651	.0830	.573	.0731	.0631	.0019	.0073	.0539
40	1.100	.1403	.978	.1247	.1092	.0036	.0120	.0936
50	1.675	.2136	1.490	.1900	.1658	.0059	.0178	.1421
60	2.331	.2972	2.085	.2658	.2350	.0089	.0244	.2017
Length of parallel middle body maximum diameter of hull.								
20	0.309	0.0436	0.275	0.0388	0.0343	0.0008	0.0039	0.0296
30	.649	.0915	.581	.0819	.0723	.0019	.0083	.0621
40	1.089	.1535	.980	1382	.1228	.0036	.0137	.1055
50	1.643	.2317	1.483	.2091	.1850	.0059	.0203	.1588
60	2.280	.3215	2.052	.2893	.2585	.0089	.0279	.2217
Length of parallel middle body twice maximum diameter of hull.								
20	0.300	0.0504	0.276	0.0464	0.0423	0.0008	0.0049	0.0366
30	.620	.1042	.569	.0956	.0872	.0019	.0104	.0749
40	1.045	.1757	.962	.1617	.1460	.0036	.0171	.1253
50	1.576	.2649	1.437	.2416	.2182	.0059	.0254	.1869
60	2.201	.3700	1.998	.3359	.3010	.0089	.0349	.2572
Length of parallel middle body three times maximum diameter of hull.								
20	0.290	0.0567	0.269	0.0526	0.0483	0.0008	0.0059	0.0406
30	.612	.1197	.560	.1095	.1001	.0019	.0125	.0857
40	1.038	.2030	.948	.1854	.1706	.0036	.0205	.1465
50	1.562	.3055	1.442	.2821	.2585	.0059	.0304	.2222
60	2.192	.4288	2.023	.3957	.3625	.0089	.0418	.3118
Length of parallel middle body four times maximum diameter of hull.								
20	0.268	0.0611	0.251	0.0572	0.0535	0.0008	0.0069	0.0458
30	.569	.1297	.532	.1212	.1121	.0019	.0146	.0956
40	.969	.2208	.902	.2056	.1917	.0036	.0240	.1641
50	1.460	.3327	1.361	.3102	.2875	.0059	.0355	.2461
60	2.050	.4672	1.909	.4351	.4030	.0089	.0488	.3453
Length of parallel middle body five times maximum diameter of hull.								
20	0.255	0.0650	0.239	0.0609	0.0557	0.0008	0.0079	0.0470
30	.552	.1408	.510	.1301	.1198	.0019	.0166	.1013
40	.938	.2392	.875	.2231	.2075	.0036	.0274	.1765
50	1.418	.3616	1.327	.3384	.3155	.0059	.0406	.2690
60	1.982	.5054	1.866	.4758	.4460	.0089	.0557	.3814

TABLE II.—*Shape coefficient and corresponding values of VL for C class airship hull.*

Air speed in m. p. h.	Shape coefficient $C=\frac{Rg/\rho}{(Vol)^{2/3}V_1^2}$	V_1L (ft.×ft./sec.).	VL (ft.×mi./hr.).
Length of parallel middle body zero.			
20	0.01587	86.6	59.0
30	.01485	129.8	88.5
40	.01438	173.1	118.0
50	.01396	216.4	147.5
60	.01302	259.7	177.0
Length of parallel middle body one-fourth maximum diameter of hull.			
20	0.01543	91.3	62.2
30	.01453	136.9	93.3
40	.01398	182.5	124.4
50	.01359	228.1	155.5
60	.01318	273.7	186.6
Length of parallel middle body one-half maximum diameter of hull.			
20	0.01529	95.9	65.4
30	.01448	143.9	98.1
40	.01414	191.8	130.8
50	.01374	239.9	163.5
60	.01354	287.8	196.2
Length of parallel middle body maximum diameter of hull.			
20	0.01637	105.3	71.8
30	.01526	158.0	107.7
40	.01458	210.7	143.6
50	.01405	263.3	179.5
60	.01362	315.9	215.4
Length of parallel middle body twice maximum diameter of hull.			
20	0.01745	124.1	84.6
30	.01587	186.1	126.9
40	.01494	248.2	169.2
50	.01426	310.3	211.5
60	.01363	372.2	253.8
Length of parallel middle body three times maximum diameter of hull.			
20	0.01715	142.9	97.4
30	.01609	214.3	146.1
40	.01547	285.8	194.8
50	.01500	357.2	243.5
60	.01463	428.6	292.2
Length of parallel middle body four times maximum diameter of hull.			
20	0.01746	161.7	110.2
30	.01620	242.4	165.3
40	.01564	323.3	220.4
50	.01501	404.2	275.5
60	.01462	484.9	330.6
Length of parallel middle body five times maximum diameter of hull.			
20	0.01639	180.4	123.0
30	.01570	270.6	184.5
40	.01539	360.9	246.0
50	.01501	451.1	307.5
60	.01478	541.2	369.0

R= Resistance of model in pounds.
L= Length of model in feet.
Vol= Volume of model in cubic feet.
V_1= Wind speed in feet per second.
V= Wind speed in miles per hour.
ρ= Air density in pounds per cubic foot.
ρ/g=0.00237 slugs per cubic foot.